

TITLE: PERFORMANCE OF LOW-MASS, SUN-TEMPERED BUILDINGS

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## PERFORMANCE OF LOW-MASS, SUN-TEMPERED BUILDINGS\*

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### ABSTRACT

A sun-tempered building is one that departs from conventional residential construction in only three respects: (1) the long side of the building faces south, (2) approximately 80% of the total window area that is ordinarily used is placed on the south side of the building, and (3) all windows are double glazed. If a house that has been so modified happens to have a concrete floor slab that is not thermally isolated by carpets, its performance may be estimated by previously reported Solar Load Ratio (SLR) correlations for thermally massive direct gain buildings. The appropriate performance vs mass sensitivity curves can be used to adjust the performance estimate. However, if no floor slab is present, the sun-tempered building has too little mass to be amenable to analysis by the standard high-mass correlations. The performance of sun-tempered buildings in the low-mass category is analyzed herein and found to be improved relative to conventional structures but inferior relative to high-mass designs.

### 1. THE CONCEPT OF SUN TEMPERING

Sun-tempered building designs were developed in order to introduce conservative mainstream builders to passive solar construction. The mainstream builder, as opposed to the innovator or early adopter of new shelter concepts, serves the mass housing market and is characterized by a reluctance to make radical changes in the design of houses he has successfully built and marketed in the past. He generally sees himself as a businessman who is primarily responsive to the demands of his customers.

As a mechanism to hold the interest of the mainstream builder, the concept of sun tempering is usually presented as a series of minor modifications to home designs that

have already been proven in the marketplace. The first step is one that must be taken during the initial planning of a new development. The long axis of each house to be sun tempered should be oriented in the east-west direction. The second step is to allot 80% of the window space that would ordinarily be used to the south side of the building. The remaining 20% would be placed mostly on the east and west sides, leaving very little or no window area to the north. The third and final step is to double glaze all windows. The cost of these modifications to the builder and his customers is small and yet a significant part of the space heating load will be displaced by direct solar gains.

In order to get a feel for the glazing areas involved in sun tempering, consider a small single-family detached residence with a 1500 ft<sup>2</sup> floor space. Typical houses of this type will have a total window area equal to about 15% of the floor space, or  $0.15 \times 1500 = 225 \text{ ft}^2$ . Placing 80% of the window area on the south side of the building yields a solar collection area of 180 ft<sup>2</sup>. At this point we can split sun-tempered buildings into two categories. Suppose, in the first case, that the home in question is built on a concrete floor slab but is otherwise of frame construction. The floor slab will be at least 4 in. thick, which is within the range usually recommended for thermal storage, and will have a gross area of 1500 ft<sup>2</sup>. Even if only half of the gross area of the slab is available for thermal storage, we still have a mass surface-to-glazing surface area ratio of

$$\frac{A_m}{A_R} = \frac{750}{180} = 4.2$$

which exceeds the reference value used for the high-mass buildings discussed in Vol. 11

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of the DOE Passive Solar Design Handbook.<sup>1</sup> Thus, although the building would be considered to be a lightweight structure, it is thermally massive relative to the small solar collection area. Sun-tempered buildings built on floor slabs or having other high-mass elements within the insulation of the building envelope are, therefore, amenable to analysis by the methods presented in the Handbook and can be expected to displace a moderate fraction of the heat load in many climates. The mass sensitivity curves provide a means for correcting performance estimates obtained from the SLR correlation for departures from the reference values of thickness (6 in.) and area ratio ( $A_m/A_g = 3$ ).

If, however, the sun-tempered building has a wood frame floor over a crawl space and there are no massive elements within the insulated shell of the structure, we have the low-mass case that represents the second category. These buildings have very little thermal storage relative to the size of the solar collection area. The most significant thermal storage medium within the structure is the gypsum board that lines the walls and the ceiling. The correlation method of the Handbook is not applicable to the analysis of these buildings because they are very sensitive to short-period weather patterns. In the next section we present the characteristics of low-mass, sun-tempered reference designs that are considered representative of this building type.

## 2. REFERENCE DESIGNS FOR LOW-MASS, SUN-TEMPERED BUILDINGS

All of the previously specified characteristics of the reference designs for high-mass direct gain buildings (see Ref. 2) apply to the present case except those pertaining to the thermal storage mass, which are replaced by the values given in Table 1.

TABLE 1  
CHARACTERISTICS OF THERMAL STORAGE MASS  
IN REFERENCE LOW-MASS, SUN-TEMPERED  
BUILDING DESIGNS

- Thermal storage capacity = 8 Btu/°F ft<sup>2</sup> of glazing.
- Gypsum board properties:  
 $k = 0.0923$  Btu/ft h °F (thermal conductivity)  
 $\rho = 50$  lb/ft<sup>3</sup> (density)  
 $c = 0.26$  Btu/lb °F (specific heat)
- Gypsum board is 3/8 in. thick.
- Gypsum board surface area is 20 times glazing area.

A gyp-board thickness of 3/8 in. is used in most wood frame houses. The properties given

in Table 1 were obtained from the ASHRAE 77 Fundamentals Handbook, and the  $A_m/A_g$  ratio of 20 was calculated for a 1500 ft<sup>2</sup> structure with a collection area of 180 ft<sup>2</sup>, assuming only the south zones were available for thermal storage. Sensitivity curves to be presented later allow the reader to obtain performance estimates based on his own assumptions concerning availability of gyp-board for thermal storage.

## 3. PERFORMANCE OF THE REFERENCE DESIGNS

Plots of Solar Savings Fraction (SSF) vs SLR for low-mass, sun-tempered buildings with and without night insulation are presented in Figs. 1, 2, and 3 for Santa Maria, Albuquerque, and Madison. The highest solar fraction observed for the case with no night insulation occurs in Albuquerque at a Load Collector Ratio (LCR) of about 72 at which a performance maximum of 0.18 exists. The SSF decreases for LCRs greater than 72 because the solar gain decreases relative to the building load. The SSF also decreases for LCRs less than 72 because further increases in solar gain are not utilizable, resulting only in overheating, and because heat losses through the solar aperture continue to increase in direct proportion to the aperture area.

The performance of the low-mass, sun-tempered building without night insulation decreases as the location is shifted to the more severe climate of Madison, dropping to a local

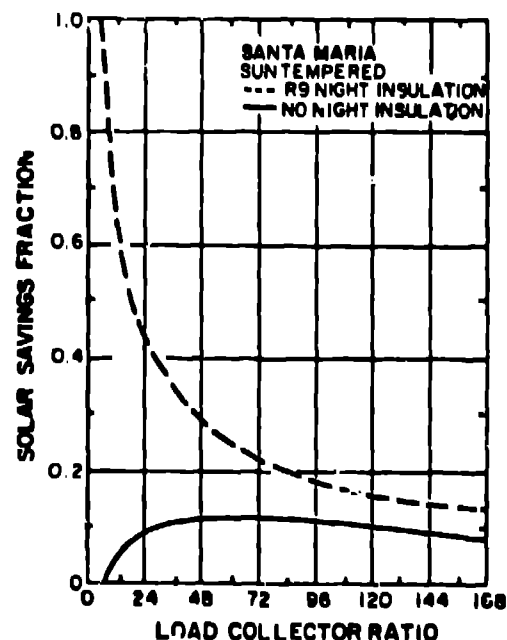


Fig. 1. Solar Savings Fraction vs Load Collector Ratio--low-mass, sun-tempered building in Santa Maria.

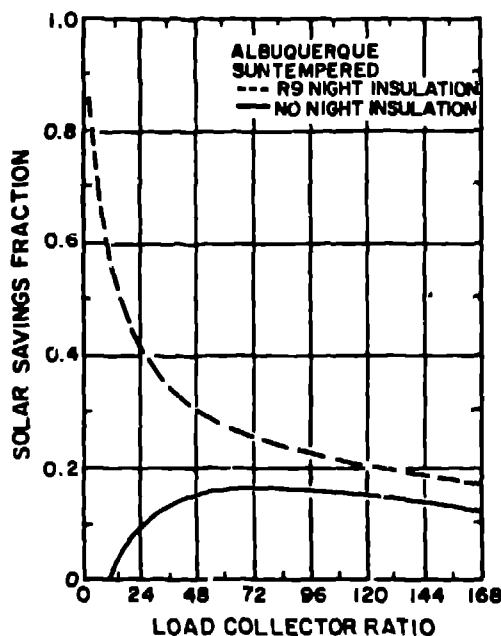


Fig. 2. Solar Savings Fraction vs Load Collector Ratio--low-mass, sun-tempered building in Albuquerque.

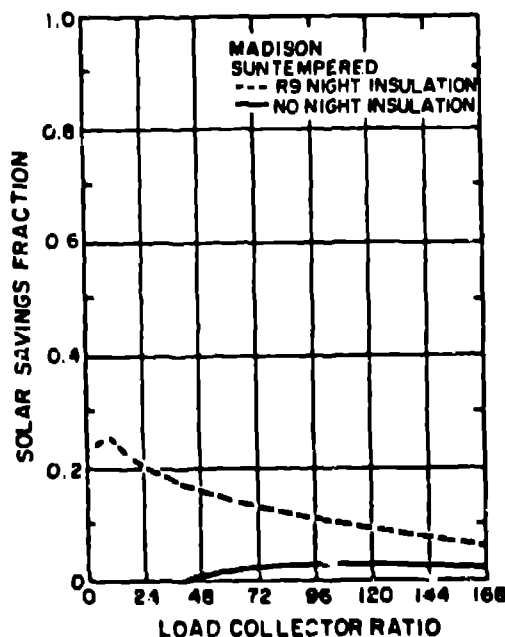


Fig. 3. Solar Savings Fraction vs Load Collector Ratio--low-mass, sun-tempered building in Madison.

maximum of  $SSF = 0.05$ . This degradation of performance in harsh winter climates was expected. However, the decrease of the maximum  $SSF$  in the milder (relative to Albuquerque) climate of Santa Maria was

unforeseen. Apparently, the low-mass, sun-tempered buildings can, at best, meet only the daytime portion of the heat load, having insufficient thermal storage for nighttime carryover. Thus, the best performance occurs in Albuquerque, where a relatively high fraction of the heating load occurs during daylight hours.

The addition of night insulation will, of course, improve the performance of sun-tempered buildings by reducing nighttime heat losses, which otherwise offset solar gains;  $SSF$ s are still well below those obtainable in higher mass structures. For night insulated, low-mass, sun-tempered buildings with  $LCRs$  of 24, a  $SSF$  of about 0.40 can be realized in Santa Maria, Charleston, and Albuquerque, about 0.30 in Nashville and Medford; and about 0.20 in Boston and Madison.<sup>3</sup>

An attempt to generate monthly  $SLH$  correlations for low-mass, sun-tempered buildings failed due to the sensitivity of these structures to short-period weather patterns. It might be possible to produce a correlation by applying the concept of solar "un-utilizability" as developed by Monsen and Klein,<sup>4</sup> but no such attempt was made.

#### 4. PERFORMANCE SENSITIVITY

**Mass Surface Area.** The effect of varying the mass area/glazing area ratio about the reference value of 20 while maintaining the 3/8-in. thickness is shown in Figs. 4, 5, and 6 for our three representative cities. Note that the performance at low  $LCRs$  can be significantly improved by adding more 3/8-in. gyp board, thereby increasing the amount of thermal storage mass. An area ratio of 40 would correspond to a 1500 ft<sup>2</sup> frame house with 180 ft<sup>2</sup> of south-facing glazing for which the gyp board in northern, as well as southern zones is available for thermal storage. The northern zones are accessible for thermal storage if a forced-air distribution system is employed or if wide, full-ceiling-height doorways are used to enhance free convective heat exchanges with the southern zones that experience direct solar gains. Figures 4 through 6 can also be used to account for thermal storage in furniture or other objects. Each increase of 10 in the  $A_m/A_g$  ratio is equivalent to an increase of 4 Btu/°F ft<sup>2</sup> of glazing in the heat capacity of the structure.

The solar absorptance of the gyp board surface has almost no effect on performance. For the sun-tempered building, the ratio of mass surface area to glazing area is so large that multiple reflections within the living space cause most of the transmitted radiation to be absorbed, regardless of interior color.

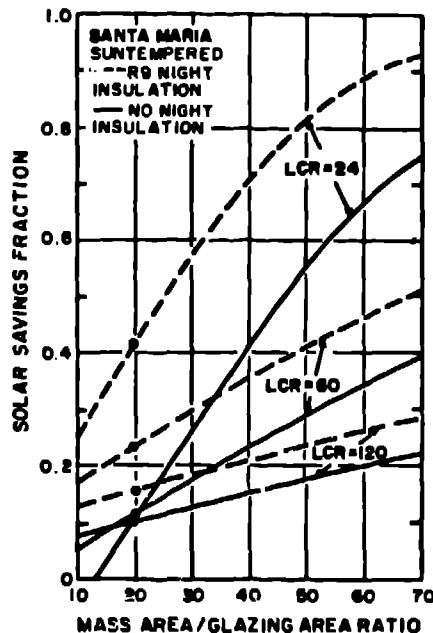


Fig. 4. Solar Savings Fraction vs mass area/glazing area ratio--Santa Maria.

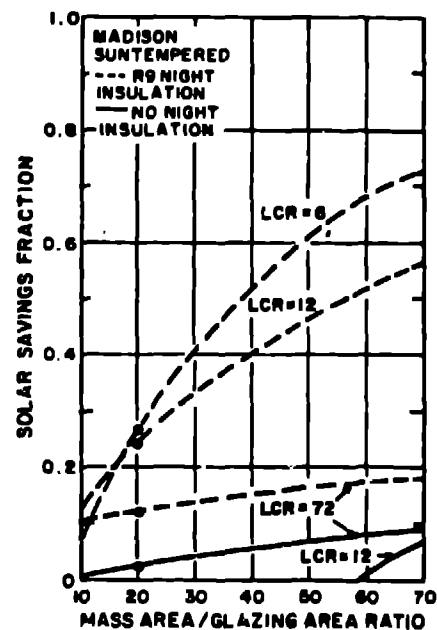


Fig. 6. Solar Savings Fraction vs mass area/glazing area ratio--Madison.

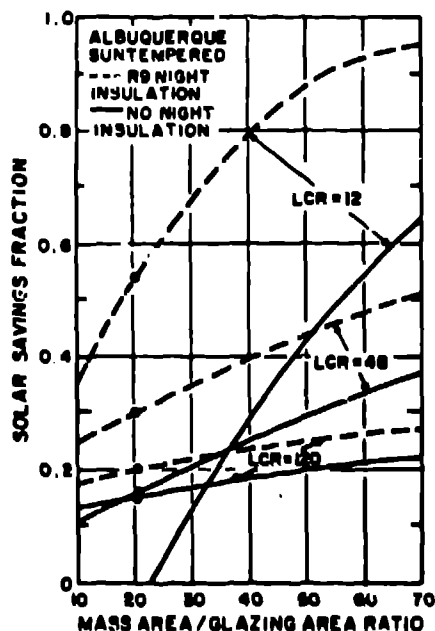


Fig. 5. Solar Savings Fraction vs mass area/glazing area ratio--Albuquerque.

Triple glazing will significantly improve the performance of low-mass, sun-tempered buildings without night insulation in any climate. Sensitivity curves for the number of glazings and other parameters can be found in Ref. 3 for seven representative US cities.

## 5. CONCLUSIONS

Low-mass, sun-tempered buildings require less auxiliary heat than the conventional structures they are intended to replace but are inferior to high-mass designs. The comfort and energy savings characteristics can be improved by making sure the northern zones are available for thermal storage either by providing a forced air distribution system or by sizing connecting apertures such that free convection maintains adequate thermal uniformity. The use of night insulation or multiple glazings can also improve performance.

## 6. ACKNOWLEDGEMENTS

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